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MARINE METEOROLOGY

On the Determination of Moisture

Gradients from Radiosonde Records

By

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Director

ABSTRACT

The humidity indicated by the rapidly rising radiosonde lags behind the true humidity of the air, making moisture gradient determinations uncertain by a factor of 4. Application of isothermal laboratory determinations of the lag to the readings may be misleading because the radiosonde, in rising through the atmosphere, usually passes from warm air to cooler air. The lag of the strip may be quite different under these circumstances. By comparison of radiosonde reports with airplane humidity soundings, it is found that in the case of the radiosonde moving from warm, dry air (about -5°C.) to cooler, moister air (about -18°C.) the lag decreases to 10 to 20 seconds. Using these lags and assuming an exponential approach to the final value, more nearly correct values of the humidity at particular heights can be computed from the radiosonde records.

I. Introduction

A vast file of upper air data has been accumulated during the past two decades from radiosonde reports from all parts of the globe. The usefulness of this material is restricted by the performance of the humidity element, which, in spite of tremendous improvements, has a few shortcomings. The particular characteristic discussed in this paper is the time of response of the electric humidity strip to changes in humidity and temperature. Knowledge of the lag of the element is of prime importance if exact values of the humidity or humidity gradients are desired.

A. Wexler (1949) has studied exhaustively the lag of the humidity strip at many temperatures and humidities and has found it to follow a very complex pattern. He gives values of the lag which show that it varies not only with the temperature and humidity, but also with the direction and magnitude of the humidity change. A point not checked is the lag time when the change in humidity is small and continuous and occurs non-isothermally. As the radiosonde in actual use always moves through regions of continually changing temperature and humidity, it is important to determine the lag under this condition. It may be reasoned that if a humidity strip is warmer than the surrounding air, by virtue of its large thermal lag, it will heat the air immediately in contact with it, thereby changing its relative humidity. If this relative humidity

change is in the same direction as the change in the outside atmosphere with height, then the effective lag of the strip is greatly reduced. However, if the two changes are in opposite directions, the effective lag is, of course, increased. It is apparent that no one correcting factor can be applied to Wexler's published lag to cover all the situations occurring in the atmosphere.

It is found upon investigation that the radiosonde always reports a more rapid decrease of mixing ratio with height than actually exists. This peculiarity arises because the radiosonde is a relative humidity measuring device and the most frequently occurring condition in a turbulently mixed layer of the atmosphere is a rise in relative humidity coupled with a decrease in temperature with height. The effect of the lag and the warming of the air next to the strip is to report relative humidities that are too small, and hence, mixing ratios that decrease with height, even when the actual mixing ratios remain constant with height. It is of interest to note at this point that a rapidly rising dew-point recorder with considerable lag would report a slight increase in mixing ratio under similar circumstances. A comparison of the relative humidity and mixing ratio values of the Portland, Maine, 1500 z, February 3, 1950 radiosonde ascent with the values obtained from a dew-point recorder carried by a DC-3 aircraft circling Portland at 1900 z is presented in Figure 1. The various features of a turbulently mixed ground

layer and the radiosonde's interpretation of the relative humidity and mixing ratio are shown clearly.

II. Determination of Effective Lag.

The lag of the humidity strip under the conditions of its ascent through the atmosphere has been determined through comparison with the humidities obtained by airplane-carried psychrographs. An airplane equipped with a humidity measuring devise can climb at a controlled, low rate. This assures that no appreciable errors due to lag occur. From an airplane ascent made at the time and place of release of a radiosonde-carrying balloon exact values of the humidity can be established at several heights. The difference between the airplane and the radiosonde values will be a measure of the effective lag with the given thermal and humidity lapse rates.

The easiest way of computing the lag is to assume that the humidity strip follows the exponential decay law as do thermometers. Apparently, the strip does not hold strictly to the law, but varies somewhat irregularly. Nevertheless, the function may be considered a sufficiently good representation of the strip's response for present purposes. Following Middleton, (1942),

$$\theta_i - \theta_e = -\beta\lambda\,(1 - e^{-t/\lambda}) \qquad (1)$$

where θ_i is the indicated relative humidity at a particular height, and θ_e, the humidity of the environment at that height.

β is the time rate of change of humidity relative to an ascending balloon, i.e., $\theta_e = \theta_1 + \beta t$, λ is the lag of the element, and t, the time interval. If θ_e and β are known from the airplane observations, then λ can be found.

This calculation has been carried out for three sets of synoptic airplane and radiosonde data available in the files of the Oceanographic Institution. The first set was obtained over Portland, Maine, on February 3, 1950. The airplane humidity measurements were obtained with a dew-point temperature recorder only a few hours after the release of the radiosonde balloon by the U. S. Weather Bureau. As a steady NW wind was blowing, no significant change in the humidity structure of the layer occurred. In the main body of the ground layer the dry-bulb temperature dropped adiabatically from -5°C. to -18°C. near the base of the ground layer inversion, and an increase with height of the relative humidity of 40% (corresponding to a slight decrease in the mixing ratio) occurred. Under these circumstances the heating of the air by the strip opposed the increasing humidity of the air and the lag increased greatly, to 165 seconds. The lag found in the lowest 130 m, where the relative humidity decreased rapidly, was 10 seconds.

On January 17, 1950, airplane observations were made in the Boston area. These have been compared to the Portland radiosonde. A lag of 105 seconds was found for the upper region of the ground layer where the relative humidity rise occurs. In

the lowest 200 m, where a humidity decrease occurs, the lag drops to 20 seconds. The temperature of the air was 1°C. near the surface and -12°C. at 1450 m.

On September 5, 1950, an airplane equipped with a psychrograph made several ascents through the ground layer of air over the island of Nantucket at about the time of release of the U. S. Weather Bureau radiosonde balloon. From the records of the two ascents, a lag of 60 seconds was computed. On this occasion the air temperature varied from 17°C. at the ground to 7°C. at 1300 m. Table I presents these findings together with the lag determined by Wexler which most nearly corresponds to the conditions found in the atmosphere.

III. Determination of the True Values of the Humidity.

The rate of change of humidity relative to the rising balloon can be computed most easily from the following form of equation (1):

$$\beta = \frac{\theta_i - \theta_1}{t - \lambda(1 - e^{-t/\lambda})}, \qquad (2)$$

where θ_1 is an initial reading of the humidity strip. This reading may be either the value obtained in the instrument shelter prior to release, or the value at the base of a column of air with a particular humidity gradient. Once the value of λ is determined, the true humidities of the air can be found at all heights up to the point where the gradient changes. The

TABLE I

Lags of humidity strips determined in flight

Date of determination	Lag, in seconds	Humidity change	Temperature °C.	Lapse rate °C/100 m	Lag determined by Wexler (1949) seconds
Feb. 3, 1950	165	increase	-5 to -18	1.0	40
	10	decrease	-4 to -5	1.0	20
Jan. 17, 1950	105	increase	-1 to -12	0.9	40
	20	decrease	1 to -1	1.0	20
Sept. 5, 1950	60	increase	17 to 12	0.9	not determined

value of λ may be selected from Table I.

For greater accuracy, further tests should be made for conditions not covered by the present tests. The values presented together with Wexler's values are sufficient to greatly improve the accuracy of mixing ratio gradients determined from radiosonde records.

The Bermuda January 18, 1951, 0300 z radiosonde is presented here as an example of a sounding that is made more intelligible by correction for the lag of the humidity element. Weather observers reported 7 - 8/10 sky coverage of stratocumulus translucidus with a base at 1000 m to 1500 m, yet the radiosonde reported a relative humidity at the cloud level of but 87%. If the radiosonde is corrected for the lag of the humidity element, a relative humidity of 97% is obtained. This value is much more compatible with the presence of clouds. A value of 60 seconds was employed for the lag in the region in which the relative humidity increased as the temperature decreased from 13°C. to 4°C. The correction modifies the mixing ratio gradient from -8×10^{-9} cm^{-1} to -1×10^{-9} cm^{-1}, a value more consistant with gradients determined from airplane observations. Figure 2 has been drawn to show the original and the corrected values of the relative humidity and the mixing ratio.

Mixing ratio gradients determined from the February 3, 1950 radiosonde reports without correction for lag are found

to be 4×10^{-9} cm^{-1}, while the gradient determined from the dew-point recorder values is 1×10^{-9} cm^{-1}. Thus the two determinations differ by a factor of 4. The September 5, 1950 radiosonde yields a value in error by a factor of only 1.5, as the strip response is faster at the higher temperatures occurring on this day.

References

Wexler, Arnold, 1949: Low-temperature performance of radiosonde electric hygrometer elements. Jour. Res., Nat. Bur. Stan. Vol. 43, pp. 49-56.

Middleton, W. E. K., 1942: Meteorological Instruments. Toronto: University of Toronto Press. 213 pp., 160 figs.

Legend

Figure 1. Comparison of radiosonde and dew-point recorder determinations of the relative humidities and mixing ratios in the turbulently mixed ground layer over Portland, Maine.

Figure 2. Original and corrected Bermuda radiosonde. The correction was computed on the basis of a 20 second lag in the lowest region and a 60 second lag in the upper region.

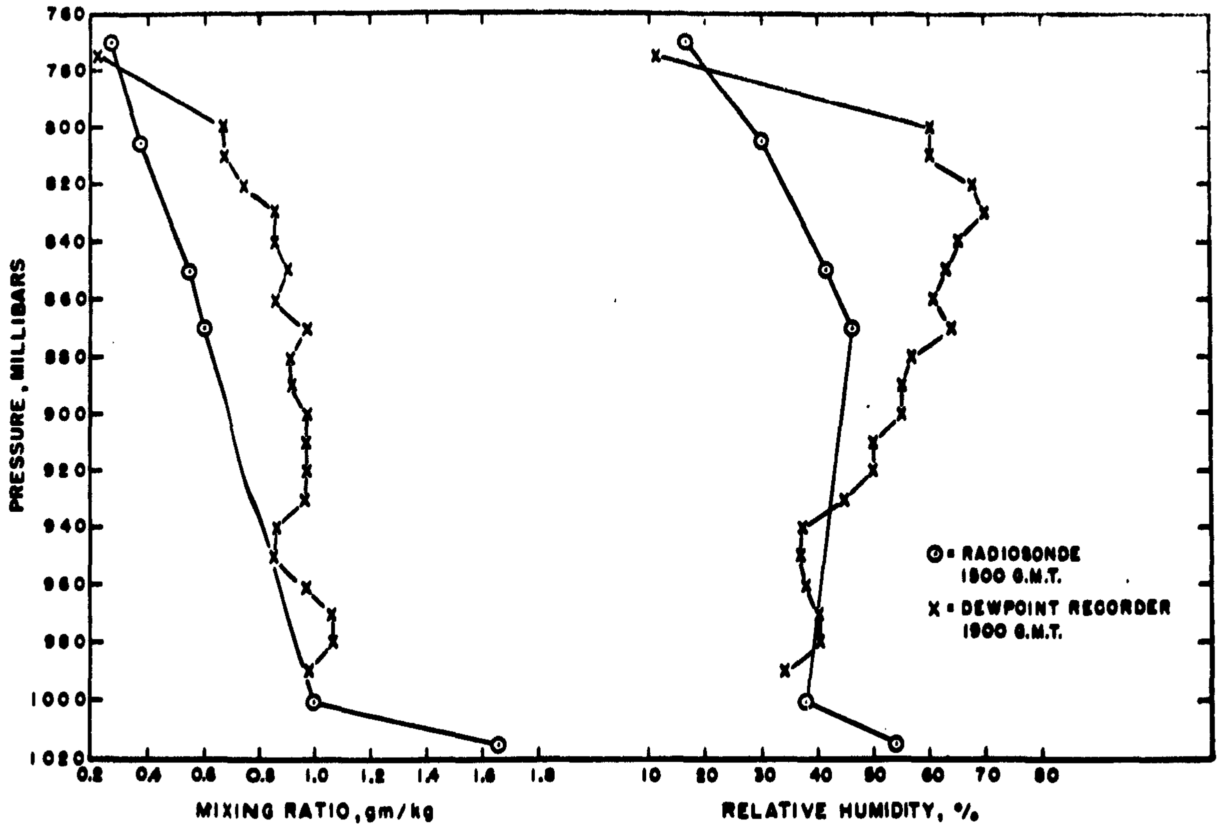
PRESSURE, MILLIBARS
MIXING RATIO, gm/kg
RELATIVE HUMIDITY, %
⊙ = RADIOSONDE 1500 G.M.T.
X = DEWPOINT RECORDER 1900 G.M.T.

FIG. 1

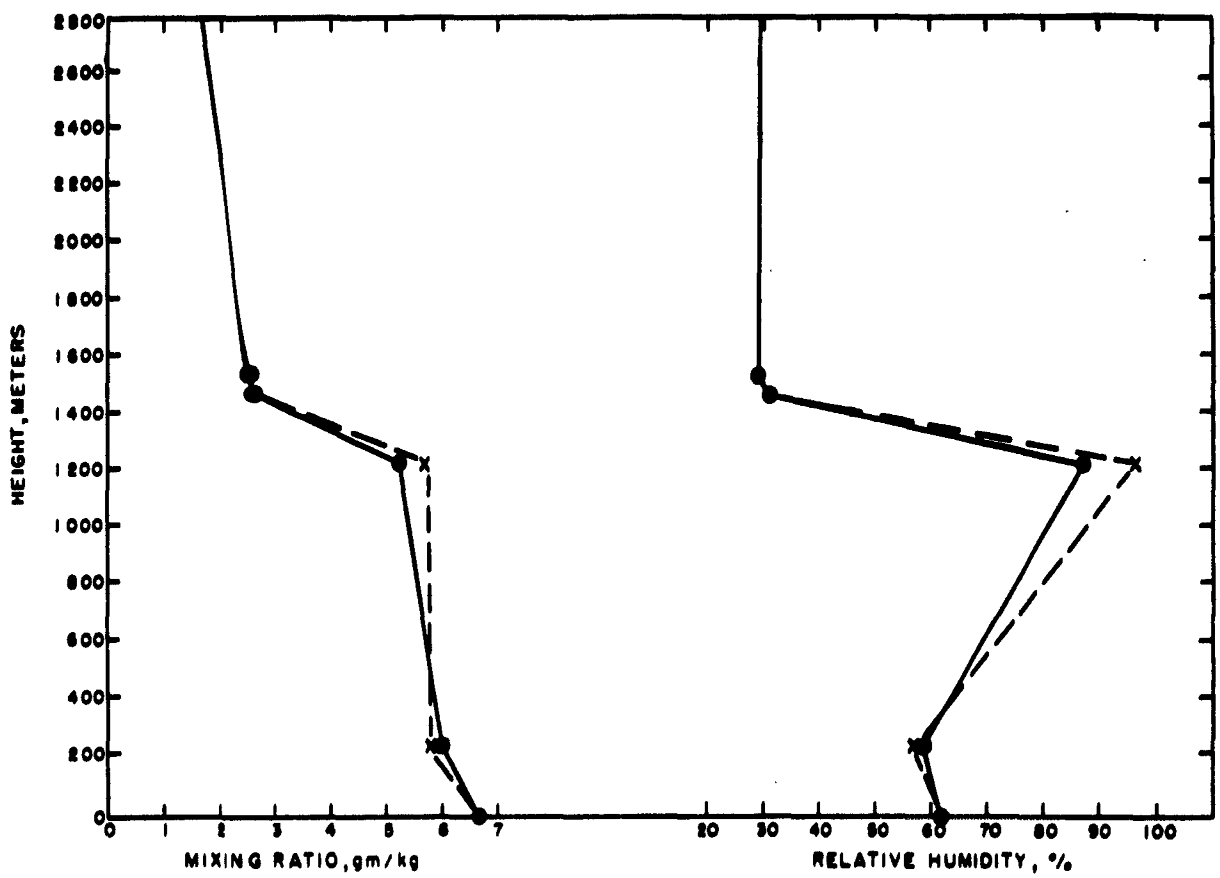
HEIGHT, METERS
MIXING RATIO, gm/kg
RELATIVE HUMIDITY, %

FIG. 2

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